

WORKING GROUP SUMMARY: ISOSPIN VIOLATION

Ulf-G. Meißner

FZ Jülich, IKP (Th), D-52425 Jülich, Germany

Abstract

I give an introduction to the problem of isospin violation and add some comments to the various topics addressed in the working group.

ISOSPIN VIOLATION: GENERAL ASPECTS

Isospin symmetry was introduced in the thirties by Heisenberg in his studies of the atomic nucleus. Since then, many particles have been found to appear in iso-multiplets, like the nucleons, the pions, the delta isobars, a.s.o. With the advent of QCD, a deeper understanding of isospin symmetry has emerged. In the limit of equal up and down current quark masses and in the absence of electroweak interactions, isospin is an exact symmetry of QCD. The intra-multiplet mass splittings allow to quantify the breaking of this symmetry, which is caused by different mechanisms (for a detailed review, see ref.[1]). First, the light quark masses are everything but equal (still, their absolute masses are much smaller than any other QCD scale and thus this breaking can be treated as a perturbation). Second, the light quarks have different charges and thus react differently to the electromagnetic (em) interactions. The em effects are also small since they are proportional to the fine structure constant $\alpha = e^2/4\pi \approx 1/137$. In the case of the pions, the mass splitting is almost entirely of em origin. This can be traced back to the absence of d-like couplings in SU(2), thus promoting the quark mass difference to a second order effect. For the nucleons, matters are different, strong and em effects are of similar size but different signs. The fact that the neutron is heavier than the proton leads to the conclusion that $m_d > m_u$, consistent with the analysis of the kaon masses. Since we know that isospin is broken - so why bother? First, the picture that has emerged from the hadron masses can not be considered complete, there is still on-going discussion about the size of the violation of Dashen's theorem, the possibility of a vanishing up quark mass to solve the strong CP problem and "strange" results from lattice gauge theory. Also, the analysis of the quark mass dependence of the baryon masses remains to be improved (for a classic, see ref.[2] and a recent study, see ref.[3]). Furthermore, only a few dynamical implications of isospin violation have been verified experimentally and a truly quantitative picture has not yet emerged. In addition, the nucleus as a many-body system offers a novel laboratory to study isospin violation. In addition, with the advent of CW electron accelerators and improved detectors, we now have experimental tools to measure threshold pion photoproduction with an unprecedented accuracy.

THE PION SECTOR

The purely mesonic sector was not touched upon in this working group, but there is one recent result which I would like to discuss. In elastic $\pi\pi$ scattering, the chiral perturbation analysis has been carried out to two loops. It was demonstrated in refs.[4,5] that the em isospin-violating effects are of the same size as the hadronic two-loop corrections. For a precise description of low energy pion reactions, it is thus mandatory to include such effects consistently. A somewhat surprising result was found in case of the scalar and the vector form factor of the pion in ref.[6]. It was shown that the em corrections to the momentum-dependence of both form factors are tiny (due to large cancellations between various contributions), much smaller than the corresponding hadronic two-loop contributions worked out in refs.[7,8]. This result remains to be understood in more detail. It is particularly surprising for the scalar form factor since it is not protected by a conserved current theorem à la Ademollo-Gatto. Only the normalization of the scalar form factor exhibits the few percent em corrections anticipated from the study of the $\pi\pi$ scattering lengths. Note, however, that the smallness of the effects of the light quark mass difference for the pion form factors has been known and understood since long[9].

THE PION–NUCLEON SECTOR

The pion–nucleon system plays a particular role in the study of isospin violation. First, the explicit chiral symmetry breaking and isospin breaking operators appear at the same order in the effective Lagrangian which maps out the symmetry breaking part of the QCD Hamiltonian, i.e. the quark mass term (restricted here to the two lightest flavors),

$$\mathcal{H}_{\text{QCD}}^{\text{sb}} = m_u \bar{u}u + m_d \bar{d}d = \frac{1}{2}(m_u + m_d)(\bar{u}u + \bar{d}d) + \frac{1}{2}(m_u - m_d)(\bar{u}u - \bar{d}d) , \quad (1)$$

so that the strong isospin violation is entirely due to the isovector term whereas the isoscalar term leads to the explicit chiral symmetry breaking. In the presence of nucleons (and in contrast to the pion case), both breakings appear at the same order. This can lead to sizeable isospin violation as first stressed in reactions involving neutral pions by Weinberg[10]. Let me perform some naive dimensional analysis for the general case (say for any given channel in πN scattering that is not suppressed to leading order). Isospin–violation (IV) should be of the size

$$\text{IV} \sim \frac{m_d - m_u}{\Lambda_{\text{hadronic}}} \approx \frac{m_d - m_u}{M_\rho} = \mathcal{O}(1\%) , \quad (2)$$

where the mass of the ρ set the scale for the non–Goldstone physics. In the presence of a close–by and strongly coupled baryonic resonance like the $\Delta(1232)$, IV might be enhanced

$$\text{IV} \sim \frac{m_d - m_u}{m_\Delta - m_N} = \mathcal{O}(2\%) . \quad (3)$$

Of course, such type of arguments can not substitute for full scale calculations. Second, there are two analyses[11,12] which seem to indicate a fair amount of isospin violation (of the order of 6...7%, which is much bigger than the dimensional arguments given above would indicate) in low–energy πN scattering, see Gibbs’ talk[13]. This can not be explained in conventional meson–exchange models by standard meson mixing mechanisms. I would also like to mention that in these two analyses the hadronic and the electromagnetic contributions are derived from different models. This might cause some concern about possible uncertainties due to a theoretical mismatch. Clearly, it would be preferable to use here one unique framework. That can, in principle, be supplied by chiral perturbation theory since electromagnetic corrections can be included systematically by a straightforward extension of the power counting. This is most economically, done by counting the electric charge as a small parameter, i.e. on the same footing as the external momenta and meson masses. The heavy baryon chiral perturbation theory machinery to study these questions to complete one–loop (fourth) order has been set up as shown by Müller[14]. It is important to perform such calculations to fourth order since one–loop graphs appear at dimension three *and* four. Furthermore, it is known from many studies that one–loop diagrams with exactly one insertion from the dimension two πN Lagrangian are (often) important. Finally, symmetry breaking (chiral and isospin) in the loops only starts at fourth order. In particular, questions surrounding the πN σ –term or neutral pion scattering off nucleons can now be addressed to sufficient theoretical precision. A first step in this direction for all channels in πN scattering was reported by Fettes[15], but a full scale one–loop calculation including all virtual photon effects still has to be done. Of particular interest is the novel relation between π^0 and π^\pm scattering off protons that is extremely sensitive to isospin violation. It should also be stressed that for such tests, it is mandatory to better measure and determine the small isoscalar πN amplitudes. Also, the relations which include the much bigger isovector amplitudes show IV consistent with the dimensional arguments given in eq.(2). I consider the “ordering schemes” discussed by Gibbs and Fettes very useful tools to pin down the strengths and sources of isospin breaking in πN scattering. This also allows to see a priori which type of measurements are necessary to obtain complete information and to what extent various reactions can give redundant information (one example is discussed by Gibbs[13]). Intimately related to this is pion–photoproduction via the final–state theorem, i.e. certain πN scattering phases appear in the imaginary part of the respective

charged or neutral pion photoproduction multipoles. Bernstein[16] stressed that in neutral pion photoproduction off protons, there are two places to look for isospin violation. One is below the π^+n threshold, which might give access to the elusive (but important) π^0p scattering length. At present, it does not appear that the original proposal of measuring the target polarization below the π^+n threshold to high precision is feasible at a machine like e.g. MAMI. The other important effect, which appears to be more easily accessible to an experiment, is the strength of the cusp at the opening of the π^+n threshold, which according to Bernstein's three-channel S-matrix analysis[16] is quite sensitive to isospin violation. Such a calculation should also be done in the framework of heavy baryon chiral perturbation theory (beyond the charged to neutral pion mass difference effects included so far). Over the last years, there has been a very fruitful interplay between experimenters and theorists particularly in the field of pion photo- and electroproduction and it is of utmost important to further strengthen this. It is a theorists dream that reactions with neutral pions (elastic scattering and photoproduction) will be measured to a high precision. An important point was stressed by Lewis[17]. In a "toy" calculation (i.e. an SU(2) approach to the strange vector form factor of the nucleon, which is clearly related to three flavor QCD), he showed that isospin-breaking effects can simulate a "strange" form factor that intrinsically vanishes in that approach. This nicely demonstrates that to reliably determine small quantities, may they be related to isospin conserving or violating operators, *all* possible effects have to be included. The recent measurements at BATES and JLAB, which seem to indicate small expectation values of the strange vector current in the proton, should therefore be reanalyzed. In this case, isospin violation appears to be a nuisance but can not be ignored.

THE NUCLEON-NUCLEON SECTOR

The only new data with respect to IV were presented by Machner[18]. He analysed recent data from COSY and IUCF for $pp \rightarrow \pi^+d$ and $np \rightarrow \pi^0d$. For exact isospin symmetry (i.e. after removing the Coulomb corrections), the pertinent cross sections should be equal (up to a Clebsch). In the threshold region, one can make a partial wave expansion and finds that the S-wave contribution α_0 shows IV of the order of 10% and no effect is observed in the P-wave terms. To my knowledge, a theoretical understanding of this effect is lacking. Despite a huge amount of efforts over the last years, a model-independent effective field theory description of pion production in proton-proton collisions has not yet been obtained. The energies involved to even produce a pion at rest are too large for the methods employed so far. More progress, however, has been made in the two-nucleon system at low energies. It is well known that IV appears in the NN scattering lengths. In the nuclear jargon, one talks about charge independence breaking (CIB) ($a_{np} \neq (a_{pp} + a_{nn})/2$ after Coulomb subtraction, where a denotes the scattering length) and charge symmetry breaking (CSB) ($a_{pp} \neq a_{nn}$ after Coulomb subtraction). These effects are naturally most pronounced at threshold. Kaplan, Savage and Wise (KSW)[19] have proposed a non-perturbative scheme that allows for power counting on the level of the nucleon-nucleon scattering amplitude. In that framework, IV (CIB and CSB) has recently been investigated[20]. It was shown that isospin violation can be systematically included in the effective field theory approach to the two-nucleon system in the KSW formulation. For that, one has to construct the most general effective Lagrangian containing virtual photons and extend the power counting accordingly. This framework allows one to systematically classify the various contributions to CIB and CSB. In particular, the power counting combined with dimensional analysis allows one to understand the suppression of contributions from a possible charge-dependence in the pion-nucleon coupling constants. Including the pions, the leading CIB breaking effects are the pion mass difference in one-pion exchange together with a four-nucleon contact term. These effects scale as αQ^{-2} , where $Q \approx 1/3$ is the genuine expansion parameter of the KSW scheme. Power counting lets one expect that the much debated contributions from two-pion exchange and $\pi\gamma$ graphs are suppressed by factors of $1/3$ and $(1/3)^2$, respectively. This is in agreement with some, but not all, previous more model-dependent calculations. The leading charge symmetry breaking is simply given by a four-nucleon contact term.

LIGHT NUCLEI

Often, the nucleus can be used as a filter to enhance or suppress certain features of reactions as they appear in free space. Furthermore, measurements on the neutron, which are necessary to get the complete information in the isospin basis (for a discussion on this topic with respect to pion photoproduction, see ref.[21]) can only be done on (preferably polarized) light nuclei. Gibbs[13] has pointed out that a measurement of charge exchange on the proton and the neutron (in forward direction and close to the interference minimum near 45 MeV) could be done in the ^3He -triton system. This would be an interesting possibility to get another handle on the elusive neutron and allow one to pin down one of the amplitudes parametrizing IV (according to the ordering scheme mentioned above). For a more detailed discussion concerning the extraction of neutron properties from the deuteron, I refer to the recent summary by Beane[22].

WHERE DO WE STAND AND WHERE TO GO

For sure, isospin symmetry is broken. However, do we precisely know the size of IV from experiment? The answer is yes and no. We have some indicative information but no systematic investigations of all pertinent low energy reactions are available. Also, one might ask the question whether the methodology, which has been used so far to extract numbers on IV, say from low energy πN scattering data, is reliable? If we assume that this is the case, we still have no deeper understanding of the mechanisms triggering IV. To my knowledge, the only machinery to consistently separate strong and electromagnetic IV is based on effective field theory. In that scheme, one can consider various reactions like elastic πN scattering, pion photoproduction or even nucleon Compton scattering to try to get a handle on the symmetry breaking operators $\sim m_d - m_u$. Also, a systematic treatment of isospin violation is mandatory for the determination of small quantities like the isoscalar S-wave scattering length or the strange nucleon form factors. Based on that, I have the following wish list for theory and experiment:

THEORY:

- The effective chiral Lagrangian calculations can and need to be improved. In particular, it is most urgent to get a handle on the so-called low-energy constants, which parametrize the effective Lagrangian beyond leading order. Sum rules, models or even the lattice might be useful here.
- A deeper theoretical understanding of certain phenomenological models (like e.g. the extended tree level model of ref.[23]) in connection with the approaches to correct for Coulomb effects would be helpful.
- The dispersion-theoretical approach should be revisited and set up in a way to properly include IV (beyond what has been done so far). For some first steps, see the talk by Oades[24].

EXPERIMENT:

- Clearly, we need more high precision data for the elementary processes, but not only for πN scattering but also for (neutral) pion photo/electroproduction.
- More precise nuclear data are also needed. Embedding the elementary reactions in the nucleus as a filter allows one to get information on the elusive neutron properties. Clearly, this refers to few-nucleon systems where precise theoretical calculations are possible.

Finally, I would like to stress again that a truly quantitative understanding of isospin violation can only be obtained by considering a huge variety of processes. While pion-nucleon scattering is at the heart of these investigations, threshold pion photoproduction or the nucleon form factors also play a vital role in supplying additional information.

ACKNOWLEDGEMENTS

I would like to thank all participants of this working group for their contributions. I am grateful to my collaborators Evgeny Epelbaum, Nadia Fettes, Bastian Kubis, Guido Müller and Sven Steininger for sharing with me their insight into this topic. Last but not least the superbe organization by Christine Kunz and Res Badertscher is warmly acknowledged.

REFERENCES

1. J. Gasser and H. Leutwyler, Phys. Rep. **C87**, 77 (1982).
2. J. Gasser, Ann. Phys. (NY) **136**, 62 (1981).
3. B. Borasoy and Ulf-G. Meißner, Ann. Phys. (NY) **254**, 192 (1997).
4. Ulf-G. Meißner, G. Müller, and S. Steininger, Phys. Lett. **B406**, 154 (1997) 154; (E) *ibid* **B407**, 434 (1997).
5. M. Knecht and R. Urech, Nucl. Phys. **B519**, 329 (1998).
6. B. Kubis and Ulf-G. Meißner, [hep-ph/9908261](#).
7. J. Gasser and Ulf-G. Meißner, Nucl. Phys. **B357**, 90 (1991).
8. J. Bijnens, G. Colangelo, and P. Talavera, JHEP **9805**, 014 (1998).
9. J. Gasser and H. Leutwyler, Ann. Phys.(NY) **158**, 142 (1984).
10. S. Weinberg, Trans. N.Y. Acad. of Sci. **38**, 185 (1977).
11. W.R. Gibbs, Li Ai and W.B. Kaufmann, Phys. Rev. Lett. **74**, 3740 (1995).
12. E. Matsinos, Phys. Rev. **C56**, 3014 (1997).
13. W.R. Gibbs, *these proceedings*.
14. G. Müller, *these proceedings*.
15. N. Fettes, *these proceedings*.
16. A.M. Bernstein, *these proceedings*.
17. R. Lewis, *these proceedings*.
18. H. Machner, *these proceedings*.
19. D.B. Kaplan, M.J. Savage and M.B. Wise, Nucl. Phys. **B534**, 329 (1998).
20. E. Epelbaum and Ulf-G. Meißner, Phys. Lett. **B467**, 284 (1999).
21. Ulf-G. Meißner, Nucl. Phys. **A629**, 72c (1998).
22. S.R. Beane, [nucl-th/9909016](#).
23. P.F.A. Goudsmit et al., Nucl. Phys. **A575**, 673 (1994).
24. G. Oades, *these proceedings*.